AD 267 314

P. O. BOX 555 OWen 6-4710

AEROPROJECTS INCORPORATED

310 EAST ROSEDALE AVENUE, WEST CHESTER, PENNSYLVANIA

November 9, 1961

Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.

Attention: RRMA-231

Via: Inspector of Naval Material
10 North 8th Street
Reading, Pennsylvania

Subject: ULTRASONIC WELDING OF REFRACTORY METALS
Progress Report No. 4
For the Period, August 1 through September 30, 1961
Bureau of Naval Weapons, Department of the Navy
Contract NOw 61-0410-c

Gentlemen:

During the period August 1 through September 30, 1961, the effects of weld energy and pulse time on the quality of welds produced in 0.005-inch molybdenum-0.5 titanium alloy were studied; clamping force levels for certain of the refractory materials were affirmed by the Standing Wave Ratio (SWR) procedure, and the use of power programming for welding tungsten was investigated. The results are presented herein.

MATERIALS

From two to eight square feet of the materials ordered previously were received. The gages of each refractory metal and the quantity received are listed below:

Refractory Material	Gage (inch)	Quantity Received (square feet)
Cb (D-31)	0.005	2
	.010	4
	.015	3
Mo-0.5 Ti	0.015	2+
	.020	1
Tungsten	0.005 (SRA)	2
	.010 (SRA)	2
Columbium	0.0005	1
Molybdenum	.0005	8
Tantalum	.0005	8

SRA: Stress-Relief Annealed

The 0.0005-inch columbium, molybdenum, and tantalum foil was purchased for use in high-temperature, interleaf-welding studies.

WELDING INVESTIGATIONS

BACKGROUND

Some degree of internal plastic deformation is commonly observed in microsections of ultrasonic welds and has been noted in weld sections of brittle materials such as beryllium. On the other hand, certain brittle materials tend to crack during ultrasonic welding. Consideration of means to eliminate this occasional cracking tendency suggests that the following mechanisms, normally operating to permit plastic flow and to inhibit cracking, can be emphasized:

1. Temperature

The achievement of temperatures above the ductile-brittle transition point prior to the application of stresses, possibly productive of cracking, can be effected by means of power and force programming designed to first generate a controlled temperature rise and subsequently to accomplish the bond.

2. Tri-Axial Restraint

Arrange the tip-element geometry to permit welding with the weld locale in compression. With the wedge-reed weld system, the welding tip excursioning in an arc may slightly reduce clamping pressure at the extremes of its arc. Basic research into the mechanism of ultrasonic welding (1, 2)* has shown that the weld is actually accomplished as a result of the interfacial shear forces resulting from the shear vibration generally at the excursion extremes. Thus, relief of the clamping force reduces both the factors productive of welding and the transversal compression; possibly all these elements contribute to a cracking tendency in certain materials. To explore this notion, a conical anvil face, with the concavity matching the estimated radius of the arc described by the tip, was fabricated to prepare a group of experimental welds.

3. Reduced Number of Stress Cycles

By decreasing the number of stress cycles to which the material is subjected during ultrasonic welding, i.e., limiting the pulse time, the build-up of crack-producing strains may be prevented.

MOLYBDENUM -0.5 TITANIUM (0.005-Inch Sheet)

Although a high degree of plastic flow (3) was obtained in the preliminary ultrasonic welding of 0.005-inch molybdenum-0.5 titanium alloy, a

*Numbers in parentheses indicate references at the end of the report.

tendency to cracking in the weld zone was observed. Since this alloy exhibits a ductile-brittle, transition-temperature* range of approximately -40 to -10°F (4), the development of brittleness during ultrasonic welding operations was, initially, considered unlikely. Further consideration of this relationship indicated that, under very high strain-rate conditions, the transition temperature, depending on the size (5) and heat-treatment of the alloy, may be in the range of 500° to 900°F. Since the strain-rate, due to vibratory stresses occurring during ultrasonic welding is probably higher than that encountered in the standard tension test, although perhaps not as great as in a Charpy Test, the possibility that this alloy becomes brittle and behaves in a manner similar to beryllium and tungsten during the early portion of the weld cycle was considered.

Ultrasonic welding of 0.005-inch molybdenum - 0.5 titanium was evaluated by measuring the tensile strength of the ultrasonic bonds, while the cracking associated with these welds was determined by metallographic examination. The cracking tendency of this material was explored as described below.

Initially, three sets of eight specimens each were welded at a clamping force of 300 pounds and energy levels of 480, 600, 720, and 840 watt-seconds. Sample welds made at these four energy levels were replicated at weld intervals of 0.3 and 0.6 seconds in each group of specimens. In the first investigation, all samples were degreased** prior to welding. The surface of the second set of eight samples was prepared for welding by electropolishing***,while the remaining specimens were degreased and welded with a concave-face anvil replacing the standard flat-surface one. The tensile strength of these welds was not determined, but they were examined metallographically by a parallel-section technique. The results of the metallographic examination as well as a description of the parallel-section technique will be presented herein under Metallography.

Samples of this alloy were also welded over a period of time at a clamping force of 300 pounds, a power level of 1200 watts and a weld interval of 0.6 seconds to establish the reproducibility or variability of the strength measurements as a function of the type of anvil surface presented to the weldment. Both a concave-face anvil and one with a standard flat surface were used in this work; the data were grouped and evaluated by anvil type. The results of these evaluations are summarized in Table 1.

---

* Strain-rate 0.04 inch/inch/second

** Degreased with Pennsalt A-27 detergent solution. (Unless otherwise specified, all specimens welded in this laboratory are degreased in this manner before welding.)

*** Electropolished in a Cr_2O_3 solution.

Table 1

VARIABILITY* OF TENSILE SHEAR DATA FOR 0.005-INCH MOLYBDENUM - 0.5 TITANIUM ALLOY AS A FUNCTION OF ANVIL TYPE

Sonotrode Tip:

Material: Astroloy
Type: 3-inch spherical

Welding Conditions:

Clamping Force: 300 pounds
Input Power: 1200 watts
Weld Interval: 0.6 seconds

ANVIL FACE	SHEAR STRENGTH Measurements (number)	Average (pounds)	Relative Std. Deviation* (percent)
Flat	22	56	30
Concave	12	57	17

*Variability expressed as the relative standard deviation which is commonly designated as the coefficient of variation.

The differences in the averages are not significant, but the decreased variability of the data for the concave anvil face is indicative of an appreciable improvement in the reproducibility of the strength measurements and, therefore, the weld quality.

The shear strength of welds in 0.005-inch material was also evaluated as a function of weld interval, or the duration of the applied pulse energy. The investigations were made at a constant energy level of 720 watt-seconds and weld intervals of 0.3 and 0.6 seconds. These results are summarized in Table 2.

Table 2

EVALUATION OF SHEAR-STRENGTH DATA FOR 0.005-INCH MOLYBDENUM - 0.5 TITANIUM ALLOY AS A FUNCTION OF WELD INTERVAL

Clamping Force: 300 pounds
Tip Material: Astroloy
Tip Radius: 3-inch spherical
Weld Energy: 720 watt-seconds

Weld Interval (seconds)	SHEAR STRENGTH DATA Measurements (number)	Average (pounds)	Relative Std. Deviation* (percent)
0.3	5	58	21
.6	6	60	43

*Variability expressed as the relative standard deviation which is commonly designated as the coefficient of variation.

Because of the limited number of measurements, the decreased variability at 0.3 seconds was not statistically significant. The decrease, however, does indicate the need for further study in this area.

TUNGSTEN (0.010-INCH SHEET)

Microhardness numbers for various gages of tungsten were determined for use in estimating the weld energy required to produce bonds in this material. These hardness measurements, as well as similar values for the other two refractory metals, are given in Table 3.

Table 3

VICKERS MICROHARDNESS VALUES FOR REFRACTORY MATERIALS

Refractory Material			Vickers Microhardness (VHN)
Designation	Gage (inch)	Condition or Source	
Tungsten	0.005	Fansteel - unrelieved	390
	.010	Fansteel - unrelieved	458
	.010	Solar (a) - stress relief annealed	348
	.010	General Electric - unrelieved	376
Mo-0.5 Ti	0.005	Arc-cast	269
	.006	Power Met.	229
	.010	Arc-cast	269
	.010	Power Met.	269
	.017	Power Met.	258
Cb (D-31)	0.005	Stock on hand prior to this program	258
	.008	New stock	246
	.015	New stock	238

(a) Material obtained from Solar Aircraft Company for another program. It was originally obtained from Fansteel in the stress-relief annealed condition.

Power Programming: The potential beneficial effect of power programming on the production of high quality welds in tungsten was indicated in Progress Report No. 3. Since then, both 0.005- and 0.010-inch tungsten have been welded at a clamping force of 500 pounds with programmed power delivery. Although only a limited number of investigations were made, an improvement in the weld strength as well as a decrease in the variability of the measurements was noted (Table 4).

Table 4

EFFECT OF POWER PROGRAMMING ON THE TENSILE-SHEAR STRENGTH OF ULTRASONIC BONDS IN TUNGSTEN SHEET (AS-ROLLED CONDITION)

Clamping Force: 500 pounds

Material		Power Programming		Shear Strength	
Source	Gage (inch)	Start (watts/second)	End	Average[a] (pounds)	Relative Std. Deviation[d] (percent)
Fansteel	0.005	.	1600/0.3[e]	23	82
		500/0.7	1600/0.3	49	29
Fansteel	.010	1200/0.7	3600/1.0	55(b)	35
		1200/0.7	3600/0.5	71	c
General Electric	.010	1200/0.7	3600/0.5	22	c

(a) N = 5
(b) N = 2 (Standard deviation estimated from relationship $S = R/R_f$, where $R_f = 1.13$)
(c) N = 1
(d) Commonly designated as the coefficient of variation
(e) Single-pulse

With power programming, the shear strength of welds in 0.005-inch tungsten, as shown in Table 4, was 49 pounds whereas without the programming system the average strength was 23 pounds; also, the variability of the data decreased by a factor of nearly 3, (i.e., from 82 to 29 percent). While the difference between the average shear strengths is not statistically significant (principally because of the limited amount of data), this difference plus the decrease in variability is indicative of the effect of programmed power delivery on the shear strength of the welds and the quality of welds in tungsten sheet.

STANDING WAVE RATIO (SWR) (1,2) STUDIES

In the present work, the SWR-ellipse area was determined at various clamping force levels for several gages of the refractory materials; this area value was then plotted against clamping force to provide curves from which clamping force values could be determined. Typical Clamping-Force - SWR (ellipse area) curves are shown in Figure 1 for several of the refractory materials studied.

Clamping-force values established previously for 0.005- and 0.010-inch molybdenum - 0.5 titanium by the threshold-peel test were confirmed. More important, however, the SWR procedure now clearly provides a convenient

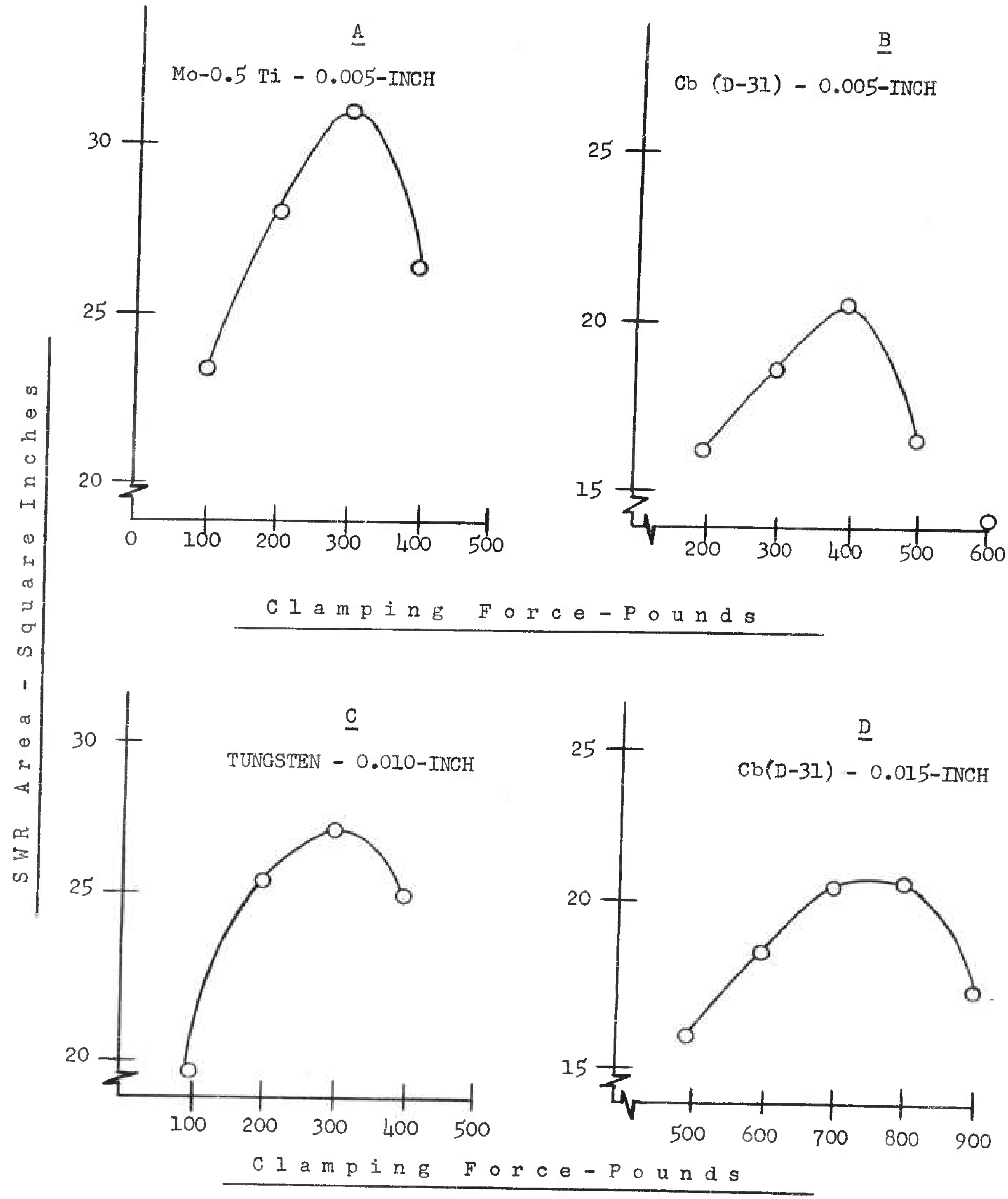

FIGURE 1: CLAMPING FORCE - SWR CURVES

means for determining clamping force values and, without much doubt, for heavier materials as well as for the gages indicated. With this procedure, the time required to establish welding conditions for the various gages of the refractory materials will be reduced.

METALLOGRAPHY

SURFACE STUDIES

Earlier evidence (6) of a possible correlation between the surface conditions of the refractory metal specimens and the quality of the weld produced led to a study of the surfaces of representative samples of columbium (D-31), molybdenum - 0.5 titanium, and tungsten. These samples were examined visually for surface irregularities, and the roughness of each surface was measured. The results are given in Table 5.

Table 5

SURFACE CONDITION OF REFRACTORY METAL SPECIMEN

Refractory Metal			Surface	
Designation	Gage (inch)	Source	Roughness (microinches)	Appearance
Cb (D-31)	0.005	DuPont	10-15	Wavy
	.005(a)	DuPont	15-25	Wavy
	.010	DuPont	5-7	Flat
	.015	DuPont	10-12	Flat
	.020	DuPont	3-5	Flat
Mo-0.5 Ti	0.005	Universal Cyclops	6-8	Flat
	.005(b)	Universal Cyclops	6-8	Flat
	.010	Universal Cyclops	4-6	Flat
Tungsten	0.005	Fansteel (c)	10-12	Wavy
	.010	Fansteel (c)	20-24	Flat
	.010	General Electric (c)	6-8	Flat
	.010	Solar (d)	10-12	Wavy

(a) Surfaces etched (Ref. P. R. #3, Figure 1).
(b) Electropolished in Cr_2O_3 solution.
(c) Material was in the as-rolled condition.
(d) Material obtained from Solar Aircraft Company for another program. It was originally obtained from Fansteel in the stress-relief annealed condition.

PARALLEL-SECTION METHOD

Specimens of 0.005-inch molybdenum - 0.5 titanium, welded in connection with the cracking study discussed previously were sectioned and mounted to permit observation of the plane section parallel with the weld interface. Progressive grinding produced sections through the sheet adjacent to the tip as well as the sheet nearest the anvil. The objective of this procedure is to progressively expose the entire weld area so that the location and type of all cracks and tears in the specimen can be determined. The results of this metallurgical examination are summarized in Table 6.

Table 6

EFFECT OF WELDING CONDITIONS AND SURFACE TREATMENT ON THE CRACKING TENDENCY OF 0.005-INCH MOLYBDENUM-0.5 TITANIUM ALLOY

Tip Material: Astroloy
Tip Radius: 3-inch spherical
Clamping Force: 300 pounds

Welding Conditions			Surface Treatment (Weld Area Appearance)		Concave Anvil Face
Energy (watt-seconds)	Power (watt)	Time (seconds)	Degreased*	Electropolished**	
480	1600	0.3	a	a	a
	800	.6	a	a	No Cracks
600	2000	0.3	cd	cd	a
	1000	.6	No Cracks	a	No Cracks
720	2400	0.3	cd	a	ab
	1200	.6	a	ab	a
840	2800	0.3	a	a	ab
	1400	.6	a	No Cracks(b)	a

* Pennsalt A-27 detergent solution
** Electropolished in Cr_2O_3 solution

a - cracked
b - bottom sheet missing
c - specimen broken during sectioning
d - weld not examined.

In general, when cracks were found, they were of two types: (1) hair-line peripheral cracks located around the circumference of the weld zone, and (2) larger fissures within the welded region. The peripheral cracks are tentatively attributed to the combined effect of thermal and vibratory stresses. The incidence of cracks surprisingly, was somewhat higher at the 0.3-second weld interval, but not significantly so; neither surface pretreatment nor the use of the concave-face anvil produced any appreciable change in the cracking tendency of this material.

FUTURE WORK

For the next bi-monthly period, the following work is planned:

1. Complete the work of determining the best clamping force for all materials and gages, using the SWR method.

2. Consider more economical and practical methods of detecting interior cracks within weldment - ultrasonic inspection is one of the methods of interest.

3. Investigate the welding machine settings and surface preparations necessary for more effective welding of columbium (D-31) in all gages from 0.005-inch to 0.020-inch.

Very truly yours,

CR Frownfelter

C. R. Frownfelter
Senior Engineer-
Staff Assistant

CRF:nj

REFERENCES

1. Aeroprojects Incorporated, "Fundamentals of Ultrasonic Welding, Phase I", RR-59-105, prepared under Contract No. NOas 58-108-c, May, 1959.

2. Aeroprojects Incorporated, "Fundamentals of Ultrasonic Welding, Phase II", RR-60-91,prepared under Contract NOas 59-6070-c, Dec., 1960.

3. Aeroprojects Incorporated, "Development of Ultrasonic Welding Equipment for Refractory Metals", TPLR-2, prepared under Contract No. AF 33 (600)-43026, August, 1961.

4. Conference, High Temperature Materials, sponsored by High Temperature Alloys Committee, Institute of Metals Division, The Metallurgical Society, American Institute of Mining, Metallurgical and Petroleum Engineers, April 16-17, 1957, John Wiley and Sons, Inc., New York, 1959.

5. Northcott, L., Metallurgy of the Rarer Metals - Molybdenum, Academic Press Inc., New York, 1956.

6. Aeroprojects Incorporated, "Development of Ultrasonic Welding Equipment for Refractory Metals", TPLR-3, prepared under Contract No. AF 33 (600)-43026, October, 1961

UNCLASSIFIED

UNCLASSIFIED